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A Computer Program for Calculating Inbreeding Coefficients in Dioecious Populations

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A Computer Program for Calculating Inbreeding Coefficients in Dioecious Populations

By Phillip C. Lowe, *research poultry husbandman, Poultry Research Branch, Animal Science Research Division, Agricultural Research Service*

SUMMARY

An average inbreeding coefficient for each successive generation of a pedigree dioecious population is obtained by calculating a weighted average of family inbreeding values. The source program of about 275 FORTRAN IV statements is designed for punched card input with identification of sire, dam, and progeny on each record. One generation is processed with each computer run. Computer output yields data on covariances within and between all full-sib families, inbreeding coefficients for all full-sib families, and an average inbreeding value for the current generation.

The CDC 6500 computer with 150,000 K (octal) word storage used for program development permitted a maximum population size of approximately 200 dam families limited to no more than nine progency per family. The number of families related to a given family is arbitrarily limited to 99. An approximation procedure is optional if this limit is exceeded.

INTRODUCTION

The level of inbreeding in a population or the rate of change in that level is of major concern to the breeder, geneticist, or researcher since progress in breeding programs and selection systems is usually confounded with the effects of inbreeding. Where pedigree records of a population are maintained, the coefficients of inbreeding of individuals, families, or generations may be calculated by various methods, such as path coefficients or covariance tables. Hand calculation of inbreeding coefficients becomes impractical as population size and number of generations increase.

Rehfeld and coworkers (1967) [1] present a path-analysis method of computing inbreeding by a computer program adapted to a moderate memory capacity computer requiring magnetic tape or disk file systems. The covariance matrix method presented herein is adapted to a very high speed computer with large central memory capacity. All input, output, and processing is accomplished with punched cards and central memory; this eliminates the need for magnetic tape or disk files.

Wright (1921) [2] showed that $F=\frac{COV\ SD}{2}$, where F is the inbreeding coefficient of the individual and *COV SD* the covariance between the individual's sire and dam. This permits a method of indexing all possible relationships among individuals in a given generation of a pedigreed population through a table or matrix of such covariances. For conservation of computer running time and memory storage, the covariances are best calculated and stored on a family basis rather than on an individual basis.

Only three types of covariances need be used: (1) covariances between members of different families, (2) covariances between members of the same family, and (3) covariances of any individual of a family with itself (this equals $1+F$, where F is the inbreeding coefficient for each member of that particular family).

Since all covariances between members of a full-sib family are equal, the average inbreeding coefficient for a given generation may then be defined as a weighted average of family inbreeding coefficients calculated as:

---

[1] Rehfeld, C. E., Bacus, J. W., Pagels, J. A., and Dipert, M. H. Computer calculation of Wright's inbreeding coefficient. Jour. Hered. 58: 81–84. 1967.

[2] Wright, Sewall. Systems of mating. I–V. Genetics 6: 111–178. 1921.

$$\bar{F}_g = \frac{\sum_{i=1}^{f} F_i n_i}{\sum_{i=1}^{f} n_i}$$

where:
F_i=the inbreeding coefficient for the ith family; n_i=the number of individuals in the ith family (i=1 . . . f); $\bar{F}_g$=the average inbreeding coefficient for a generation.

For purposes of clarification, an example of a simple five-generation pedigree with punched card input and output and printed output appears on page 4. Following the example are sections containing the flow chart, glossary of fortran variables, and the source program.

DESCRIPTION OF PROGRAM

The source program, consisting of approximately 275 FORTRAN IV statements,[3] is designed to read and process pedigree information from punched cards. Individual animals are assigned family codes by the program according to their full-sib families. Relationships among all coded families are determined and included in the printed and punched output. As subsequent generations are processed, one generation per computer run, the punched output from the previous generation containing coded families and covariances between them must also be read in and stored. The relationship between any two coded families of the current generation is then determined by the relationships among their parents.

The maximum size population that can be processed is limited by the computer's storage capacity, number of generations to be processed, and numbers of full-sib families in a given generation. Large computers with storage capacities of 50 to 55K words accommodate populations having as many as 200 full-sib families. For smaller computers, the arrays specified in the DIMENSION statement and listed in the glossary section must be decreased in size to stay within the limits of the computer's storage capacity. Central memory and running time requirement may also be materially reduced by the use of effective parents only (those parents represented by their progeny in the breeding nucleus of the next generation); this enables larger populations to be processed by a computer of given size. The program arbitrarily limits the maximum number of families related to a given family to 99 and the maximum number of dams mated to a given sire to nine.

If either limit is exceeded, an error message is printed. To avoid exceeding the maximum number of related families, the user may specify a minimum covariance between families below which families are assumed to be unrelated. An average of these small excluded covariances is obtained and appears in the summary of the printed output. A simple method is provided, as explained under "Preparation of parameter cards," for inputting this value into the subsequent generation where it is used where required, as part of the inbreeding coefficient of families in that generation. All covariances that are zero or are smaller than the covariance default value specified in parameter card No. 1 are omitted from the covariance matrix. This procedure, which is designed to reduce computer storage requirements, permits the use of two rectangular two dimensional arrays, IR and IC, for storage of the identification of related families and their covariance values, respectively.

PREPARATION OF PARAMETER CARDS

1. Parameter card No. 1.

Columns	*Description*
1–3	Generation number
4–6	Number of cards in pedigree deck
7–9	Estimated maximum number of families related to a given family—limit set at 99 in program
10–12	Estimated maximum number of full-sib families
13–15	Estimated maximum number of full-sib families plus 1
16–19	Covariance default level—minimum desired covariance multiplied by 4
20–23	Average value of excluded covariances in previous generation

---

[3] Control Data 6400/6500/6600 Computer Systems, FORTRAN Reference Manual, Publication No. 601749008. 1967.

2. Parameter card No. 2. Columns 1 to 6 equal IBLANK, a data word used to check on the number of cards contained in the pedigree deck.
3. Parameter card No. 3 is a blank trailer card.

PREPARATION OF PEDIGREE AND DATA DECKS

1. A pedigree deck containing identification of sire, dam, and progeny in three four-digit identification fields is prepared for each generation. One punched card is required for each individual progeny in the population. The source program, as listed on p. 14, is written for a data format that provides identification for sire in columns 5 to 8 and identification for dam in columns 11 to 14 and identification for progeny in columns 17 to 20. Alternative data formats in the pedigree deck may easily be accommodated by appropriate changes in FORMAT statement No. 104. The pedigree deck must be sorted by dams within sires in ascending order. Comment cards and explanatory statements to assist the user in preparation of input decks appear at frequent intervals in the source program and in the printed computer output.
2. A data deck containing family codes, a covariance matrix, and family inbreeding coefficients is produced by the computer as a part of the output after the processing of each generation. This deck is regarded as output relative to the generation currently being processed. But it must be rearranged and prepared as input to accompany the new pedigree deck during processing of the subsequent generation.

The punched output (data deck) for each generation consists of three sections each separated by a blank card. To rearrange this output as input for the next generation: (1) Remove the last section of usually 25 cards or less and discard the blank card preceding it; (2) remove the blank card separating section one (30 cards or less) and section two and insert section three at that location in the deck. No data deck is necessary for the processing of the first generation. The order of input decks is outlined below.

First generation
1. Source deck
2. Parameter card No. 1
3. Pedigree deck
4. Parameter card No. 2

Second and later generations
1. Source deck
2. Parameter card No. 1
3. Pedigree deck
4. Parameter card No. 2
5. Data deck—reorganized as discussed above
6. Parameter card No. 3

ERROR MESSAGES

The program provides for four types of error messages as follows:

1. PARAMETER CARD NO. 2 OMITTED OR INCORRECT VALUE FOR NUMBER OF CARDS IN PEDIGREE DECK
   This message is printed during processing time if parameter card No. 2 is erroneously placed or omitted or when the incorrect value for the number of cards in the pedigree deck is punched into columns 4 to 6 of parameter card No. 1. Processing is terminated when this condition is encountered. To correct this condition, recount cards in pedigree deck and check for presence of parameter card No. 2.
2. INVALID PEDIGREE—PREVIOUS GENERATION PROGENY CODE OF SIRE=*ss*, OF DAM=*dd*, CURRENT GENERATION PROGENY CODE OF INDIVIDUAL=*ii*
   This message is printed during processing time if a search of the covariance matrix reveals that either or both parents of an individual in the current generation were not present in the previous generation. (The notations *ss* and *dd* represent the sire's and dam's family code, respectively, if they are present in the previous generation, otherwise the value will be zero. The symbol *ii* represents the progeny code of an individual in the current generation.) After this interruption, processing continues with the next family. The suggested remedy is to correct the pedigree error and rerun the previous generation.
3. NUMBER OF RELATED FAMILIES EXCEEDS *xx*, PROGENY CODE OF NEXT RELATED FAMILY=*cc*
   The message occurs when the number of families related to a given family exceeds the value placed in columns 7 to 9 of parameter

card No. 1. Here *xx* equals the maximum number of related families, and *cc* is the progeny code of the next family in the covariance matrix. The problem is eliminated by increasing the magnitude of the covariance default value. Processing is not interrupted.

4. SIRE *xx* MATED TO MORE THAN 9 DAMS

   The statement occurs when there are more than nine full-sib families within one sire family. The sire is identified by the value *xx*, which is the sequential number of the sire in the pedigree of the current generation. Processing is terminated.

EXAMPLE OF CARD INPUT AND OUTPUT FOR A FIVE-GENERATION POPULATION

Identification Nos. for a five-generation pedigree population used in the example on the following pages are as follows:

	Identification Nos.		
Generation	*Sire*	*Dam*	*Progeny*
1	115	2528	163
	117	2617	8020
2	163	8020	23
			24
			30
3	30	23	1531
			1535
			1536
		24	1541
4	1531	1536	1540
			1542
			1543
	1535	1541	1622
			1626
5	1540	1622	23
	1626	1542	15
		1543	12

Input for First Generation

```
Program                          (Source Deck)
0010020020020030000000O          (Param. Card No. 1)
      115   2528   163           (Pedigree Deck)
      117   2617  8020
IBLANK                           (Param. Card No. 2)
EOF                              (End of File Card)
```

Punch Output From First Generation

```
2 PROGENY CODES DERIVED FROM 2
     FAMILIES OF FIRST GEN.

  163   118020   21
Blank Card
1000010000
 1  11  5000
 1  21  5000
```

Input for Second Generation

```
Program
0020030020020030000000O
      163   8020     23
                     24
                     30
IBLANK                               |
 2 PROGENY CODES DERIVED             |
  FROM 2 FAMILIES OF FIRST           |
           GEN.                      | DATA
  163   118020   21                  |   DECK
1000010000                           |
 1  11  5000                         |
 1  21  5000                         |
Blank Card    (Param. Card No. 3)
EOF
```

Punch Output From Second Generation

```
 3 PROGENY CODES DERIVED FROM
     1 FAMILY OF SECOND GEN.
23   11   24   11   30   11
Blank card
 1  11  5000
Blank card
10000
```

Input for Third Generation

```
Program
00300400200200300000000
        30      23   1531
                     1535
                     1536
                24   1541
IBLANK
  3 PROGENY CODES DERIVED FROM
      1 FAMILY OF SECOND GEN.
  23   11   24   11   30   11
10000
 1   11   5000
Blank card
EOF
```

Punch Output From Third Generation

```
  4 PROGENY CODES DERIVED FROM
      2 FAMILIES OF THIRD GEN.
1531   111535   111536   111541   12
Blank card
 2  11  7500  12  6250
 2  12  7500  11  6250
Blank card
12500  12500
```

Input for Fourth Generation

```
Program
00400500200200300000000
     1531    1536    1540
                     1542
                     1543
     1535    1541    1622
                     1626
IBLANK
  4 PROGENY CODES DERIVED FROM
      2 FAMILIES OF THIRD GEN.
1531   111535   111536   111541   12
1250012500
 2  11  7500  12  6250
 2  12  7500  11  6250
Blank card
EOF
```

Punch Output From Fourth Generation

```
5 PROGENY CODES DERIVED FROM 2
      FAMILIES OF FOURTH GEN.
1540   111542   111543   111622   211626   21
Blank card
 2  1110000  21  6875
 2  21  9375  11  6875
Blank card
1375013125
```

Input for Fifth Generation

```
Program
00500300300300400000000
     1540  1622       23
     1626  1542       15
           1543       12
IBLANK
5 PROGENY CODES DERIVED FROM 2
      FAMILIES OF FOURTH GEN.
1540   111542   111543   111622   211626   21
1375013125
 2  1110000  21  6875
 2  21  9375  11  6875
Blank card
EOF
```

Punch Output From Fifth Generation

```
3 PROGENY CODES DERIVED FROM 3
      FAMILIES OF FIFTH GEN.
  23   11   15   21   12   22
Blank card
 3  1110156  21  8281  22  8281
 3  2110156  11  8281  22  9218
 3  2210156  11  8281  21  9218
Blank card
134371343713437
```

FACSIMILE OF COMPUTER PRINTOUT OF FIVE-GENERATION EXAMPLE

Printed Output From First Generation

```
2 PROGENY CODES DERIVED FROM 2 FAMILIES OF FIRST GEN.
CODE CODE CODE CODE CODE
11   163  21  8020
CURRENT GENERATION RELATED FAMILIES AND COVARIANCES WITHIN AND BETWEEN FAMILIES FOLLOW.
 NUMBER
OF REL. FAM.   FAM. COV.   FAM. COV.
     1          11 5000
     1          21 5000
THE FOLLOWING ARE FAMILY INBREEDING COEFFICIENTS FOR THE CURRENT GENERATION.
.0000 .0000
```

Printed Output From Second Generation

```
3 PROGENY CODES DERIVED FROM 1 FAMILY OF SECOND GEN.
CODE   CODE   CODE   CODE   CODE
11   23   11   24   11   30
CURRENT GENERATION      =2
NUMBER OF MASTER CARDS=3
PUNCH OUTPUT FROM 2 FAMILIES IN PREVIOUS GEN. HAS BEEN READ IN AND STORED.
CURRENT GENERATION RELATED FAMILIES AND COVARIANCES WITHIN AND BETWEEN FAMILIES FOLLOW.
NUMBEROF REL. FAM.  FAM.COV.FAM.COV.
        1             11 5000
THE FOLLOWING ARE FAMILY INBREEDING COEFFICIENTS FOR THE CURRENT GENERATION.
.0000
---SUMMARY FILE---SUMMARY FILE---
GENERATION NO.           =2
NUMBER OF INDIVIDUALS =3
NUMBER OF SIRES          =1
NUMBER OF DAMS           =1
NUMBER OF INVALID PED.=0
AVERAGE NUMBER OF RELATED FAMILIES IN THIS GEN.      =1.0
NUMBER OF DROPPED COVARIANCES—CURRENT GENERATION=0.0
AVERAGE DROPPED COVARIANCE—PREVIOUS GENERATION      =0.0000
AVERAGE DROPPED COVARIANCE—CURRENT GENERATION      =0.0000
AVERAGE PERCENT INBREEDING—CURRENT GENERATION      =0.0000
```

Printed Output From Third Generation

```
4 PROGENY CODES DERIVED FROM 2 FAMILIES OF THIRD GEN.
CODE     CODE     CODE     CODE
11  1531  11  1535  11  1536  12  1541
CURRENT GENERATION      =3
NUMBER OF MASTER CARDS=4
PUNCH OUTPUT FROM 1 FAMILY IN PREVIOUS GEN. HAS BEEN READ IN AND STORED.
CURRENT GENERATION RELATED FAMILIES AND COVARIANCES WITHIN AND BETWEEN FAMILIES FOLLOW.
 NUMBER
OF REL. FAM.    FAM. COV.    FAM. COV.
     2          11 7500      12 6250
     2          12 7500      11 6250
THE FOLLOWING ARE FAMILY INBREEDING COEFFICIENTS FOR THE CURRENT GENERATION.
.2500 .2500
---SUMMARY FILE---SUMMARY FILE---
GENERATION NO.           =3
NUMBER OF INDIVIDUALS =4
NUMBER OF SIRES          =1
NUMBER OF DAMS           =2
NUMBER OF INVALID PED.=0
AVERAGE NUMBER OF RELATED FAMILIES IN THIS GEN.      =2.0
NUMBER OF DROPPED COVARIANCES—CURRENT GENERATION=0.0
AVERAGE DROPPED COVARIANCE—PREVIOUS GENERATION      =0.0000
AVERAGE DROPPED COVARIANCE CURRENT GENERATION= 0. 0000
AVERAGE PERCENT INBREEDING—CURRENT GENERATION=25. 0000
```

Printed Output From Fourth Generation

```
5 PROGENY CODES DERIVED FROM 2
      FAMILIES OF FOURTH GEN.
CODE     CODE     CODE     CODE     CODE
11 1540  11 1542  11 1543  21 1622  21 1626
CURRENT GENERATION              =4
NUMBER OF MASTER CARDS          =5
PUNCH OUTPUT FROM 2 FAMILIES IN
    PREVIOUS GEN. HAS BEEN READ IN
    AND STORED.
CURRENT GENERATION RELATED FAM-
    ILIES AND COVARIANCES WITHIN
    AND BETWEEN FAMILIES FOLLOW.
  NUMBER OF
   REL. FAM.    FAM. COV.   FAM. COV.
        2         1110000      21 6875
        2         21 9375      11 6875
THE FOLLOWING ARE FAMILY IN-
    BREEDING COEFFICIENTS FOR THE
    CURRENT GENERATION.
.3750 .3125
---SUMMARY FILE---SUMMARY FILE---
GENERATION NO.             =4
NUMBER OF INDIVIDUALS =5
NUMBER OF SIRES            =2
NUMBER OF DAMS             =2
NUMBER OF INVALID PED.=0
AVERAGE NUMBER OF RE-
    LATED FAMILIES IN THIS
    GENERATION.                  =2. 0
NUMBER OF DROPPED COVARI-
    ANCES—CURRENT GENERA-
    TION.                        =0. 0
AVERAGE DROPPED COVARI-
    ANCE—PREVIOUS GENERA-
    TION.                        =0. 0000
AVERAGE DROPPED COVARI-
    ANCE—CURRENT GENERA-
    TION.                        =0. 0000
AVERAGE PERCENT INBREED-
    ING—CURRENT GENERA-
    TION.                        =35. 0000
```

Printed Output From Fifth Generation

```
3 PROGENY CODES DERIVED FROM 3
    FAMILIES OF FIFTH GEN.
     CODE     CODE     CODE
     11   23  21   15  22   12
     CODE     CODE     CODE
CURRENT GENERATION      =5
NUMBER OF MASTER CARDS=3
PUNCH OUTPUT FROM 2 FAMILIES IN
    PREVIOUS GEN. HAS BEEN READ IN
    AND STORED.
CURRENT GENERATION RELATED FAM-
    ILIES AND COVARIANCES WITHIN
    AND BETWEEN FAMILIES FOLLOW.
 NUMBER OF
 REL.
 FAM.  FAM. COV.  FAM. COV.  FAM. COV.
  3     1110156    21 8285    22 8281
  3     2110156    11 8281    22 9218
  3     2210156    11 8281    21 9218
THE FOLLOWING ARE FAMILY INBREED-
    ING COEFFICIENTS FOR THE CUR-
    RENT GENERATION.
.3437 .3437 .3437
---SUMMARY FILE---SUMMARY FILE---
GENERATION NO             =5
NUMBER OF INDIVIDUALS =3
NUMBER OF SIRES           =2
NUMBER OF DAMS            =3
NUMBER OF INVALID PED.=0
AVERAGE NUMBER OF RELATED
    FAMILIES IN THIS GEN.      =3. 0
NUMBER OF DROPPED COVARI-
    ANCES—CURRENT GENERA-
    TION                       =0. 0
AVERAGE DROPPED COVARI-
    ANCE—PREVIOUS GENERA-
    TION                       =0. 0000
AVERAGE DROPPED COVARI-
    ANCE—CURRENT GENERA-
    TION                       =0. 0000
AVERAGE PERCENT INBREED-
    ING—CURRENT GENERA-
    TION                       =34. 3700
```

GLOSSARY OF FORTRAN VARIABLES

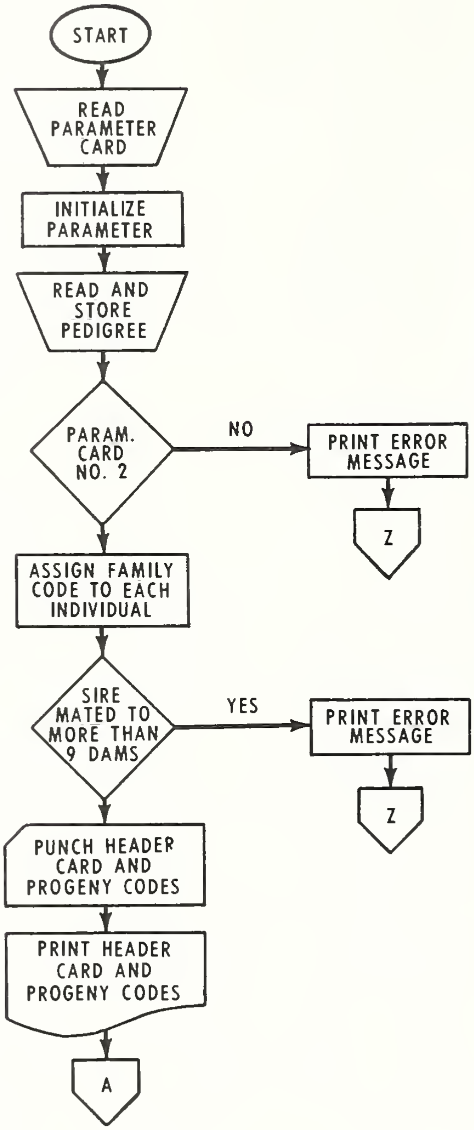
Variable	*Type* [1]	*Definition*
ACCNUM	R	Number of covariances below covariance default value
AVDROP	R	Average defaulted covariance—previous generation
AVGDRP	R	Average defaulted covariance—current generation
AVGINB	R	Average percent inbreeding—current generation
AVNODR	R	Average number of defaulted covariances per family in the current generation
AVNORL	R	Average number of families related to a given family of the current generation
COEFF	R (D,E)	Family inbreeding coefficients—current generation
COV	R	Sum of covariances among the parents of related families
COVACC	R	Sum of defaulted covariances—current generation
COVDEF	R	Covariance default value (covariance X 4)
CV	R	Covariance between any two families
D	R	Number of individuals over which inbreeding is averaged
D1	R	Number of families in the current generation
D2	R	Number of related families with covariances exceeding the default value
FCODEI	I (D)	Stored family codes of previous generation
FCODEP	I (D)	Progeny codes representing families of the current generation
I	I	DO loop index
IBLANK	I (DATA)	Value defined in the DATA statement
IBLK	I	Dummy variable
IC	I (D)	Covariance between families in the previous generation
ICOV	I (D)	Covariance between any two families of the current generation
IDAM	I (D)	Identification of dam
IDIO	I	Part of family code designating sire line
IFAMD	I (D)	Code of dam family
IFAMS	I (D)	Code of sire family
IGEN	I	Generation number of current generation
INBR	I	DO loop index—number of related families
INBRDC	I (D, E)	Covariances within families of the current generation
INBRDP	I (D)	Covariances within families of previous generation
INBSUM	I	Summation of weighted family inbreeding values
IND	I (D)	Identification of individual or progeny
INDWIN	I (D)	Number of progeny per full-sib family
IP1	I	Subscript used in a DO loop
IR	I (D)	An array of families related to a given family of the previous generation
IREL	I (D)	An array of families related to a given family of the current generation
ISIRE	I (D)	Identification of sire
ISTORI	I (D, E)	Individual's identification associated with family code of the previous generation
ISTORP	I (D, E)	Individual's identification associated with family code of the current generation
I1	I	DO loop subscript—progresses from 1 to NUMFPI
J	I	DO loop index
JD10	I	Variable used in establishing values for family codes
JP	I	DO loop index—number of full-sib families in current generation
JP1	I	Subscript value

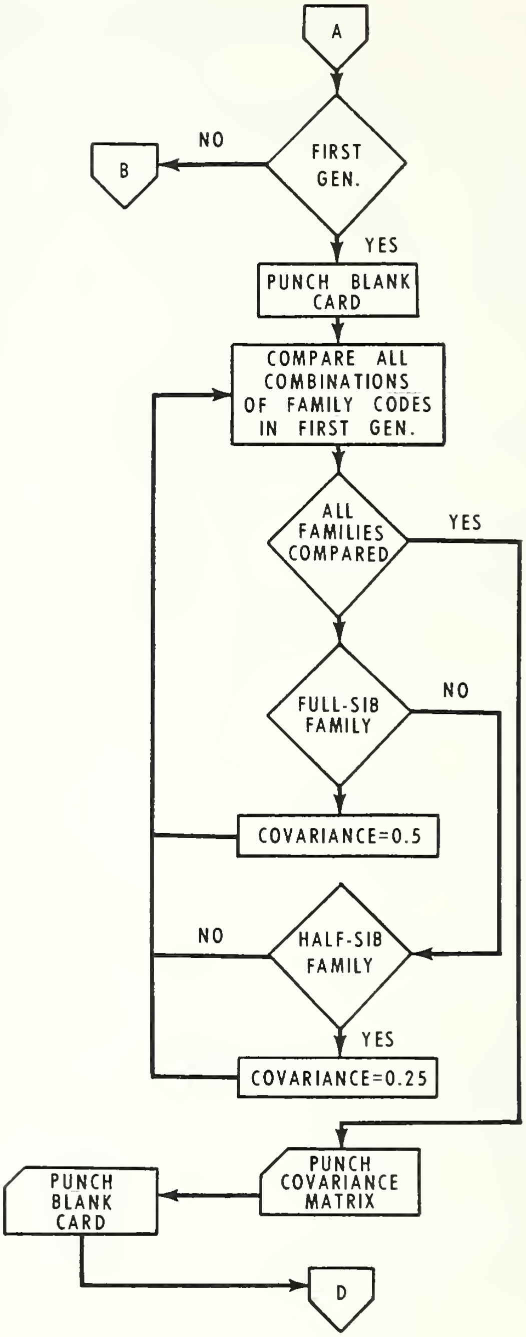
See footnote at end of glossary.

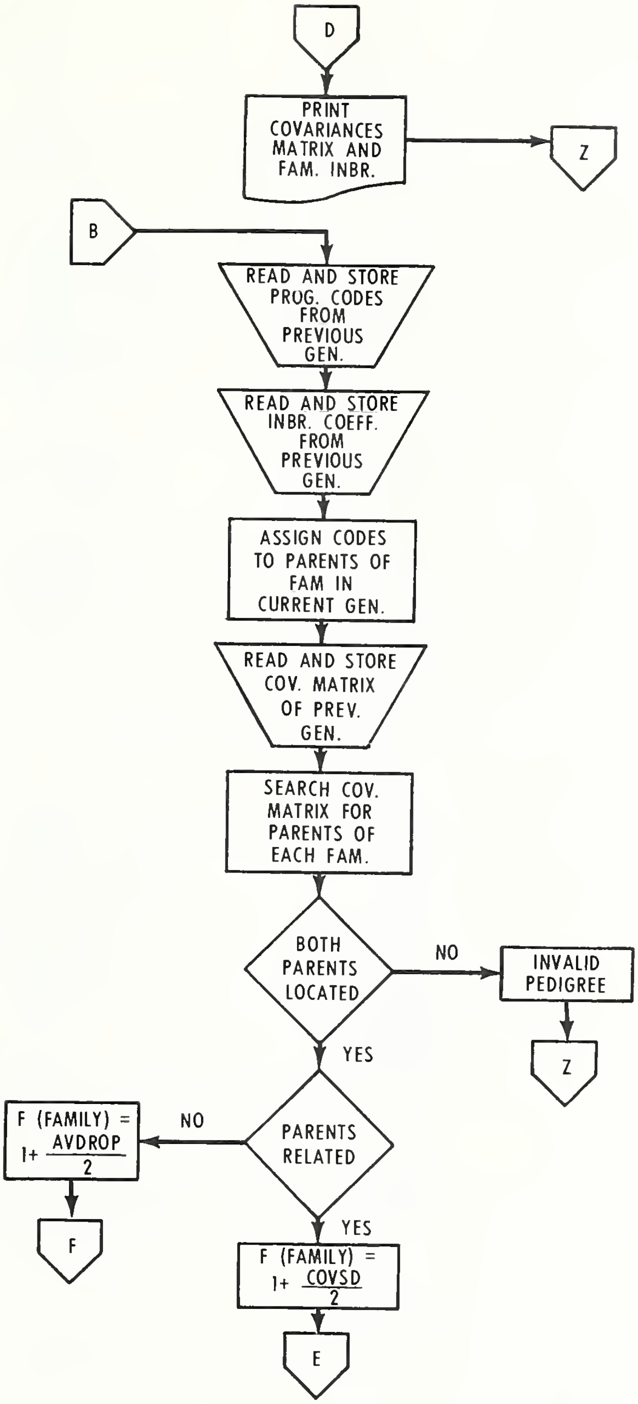
Variable	*Type* [1]	*Definition*
K	I	Counter—number of related families
KACCUM	I	Cumulative number of related families per generation
KCOUNT	I	DO loop parameter—number of full-sib families in current generation
L	I (D)	A control variable assigned to number of related families
LIMIT	I	DO loop parameter—number of related families
LIMITD	I	DO loop parameter—number of families related to female parent's family
LIMITS	I	DO loop parameter—number of families related to male parent's family
LISTRD	I	DO loop index—number of covariances among families related to dam
LISTRS	I	DO loop index—number of covariances among families related to sire
LS	I	DO loop index—number of full-sib families in current generation
LT	I	DO loop index—number of full-sib families in previous generation
LU	I	DO loop index—number of full-sib families in previous generation
LVALUE	I	Implied DO loop parameter—number related families
LI	I	Implied DO loop index—number related families
M	I	Implied DO loop index—number related families
MALES	I	Number of full-sib families in current generation
MATCHD	I	Subscript—number families related to dam
MATCHS	I	Subscript—number families related to sire
N	I	DO loop index
ND	I	Number of families in covariance table
NEWFAM	I (D)	Family currently being checked through covariance table
NFC	I	Number of full-sib families in current generation
NFLD10	I	Test variable used in detecting full- or half-sib families
NFND10	I	Test variable used in detecting full- or half-sib families
NFP	I	Number full-sib families in previous generation
NI	I	Number of individuals in current generation
NIOLD	I	Number of individuals in previous full-sib family
NIP	I	Number of individuals in previous generation
NIP1	I	NIP+1
NM	I	Number of cards in pedigree deck
NMP1	I	NM+1
NUMFAM	I	Estimated maximum number of full-sib families in current generation
NUMFP1	I	NUMFAM+1
NUMINV	I	Number of invalid pedigrees
NUMREL	I	Maximum number of related families expected
TOTINB	R	Sum of inbreeding coefficients in all full-sib families
X	R	Inbreeding in parents of a given family

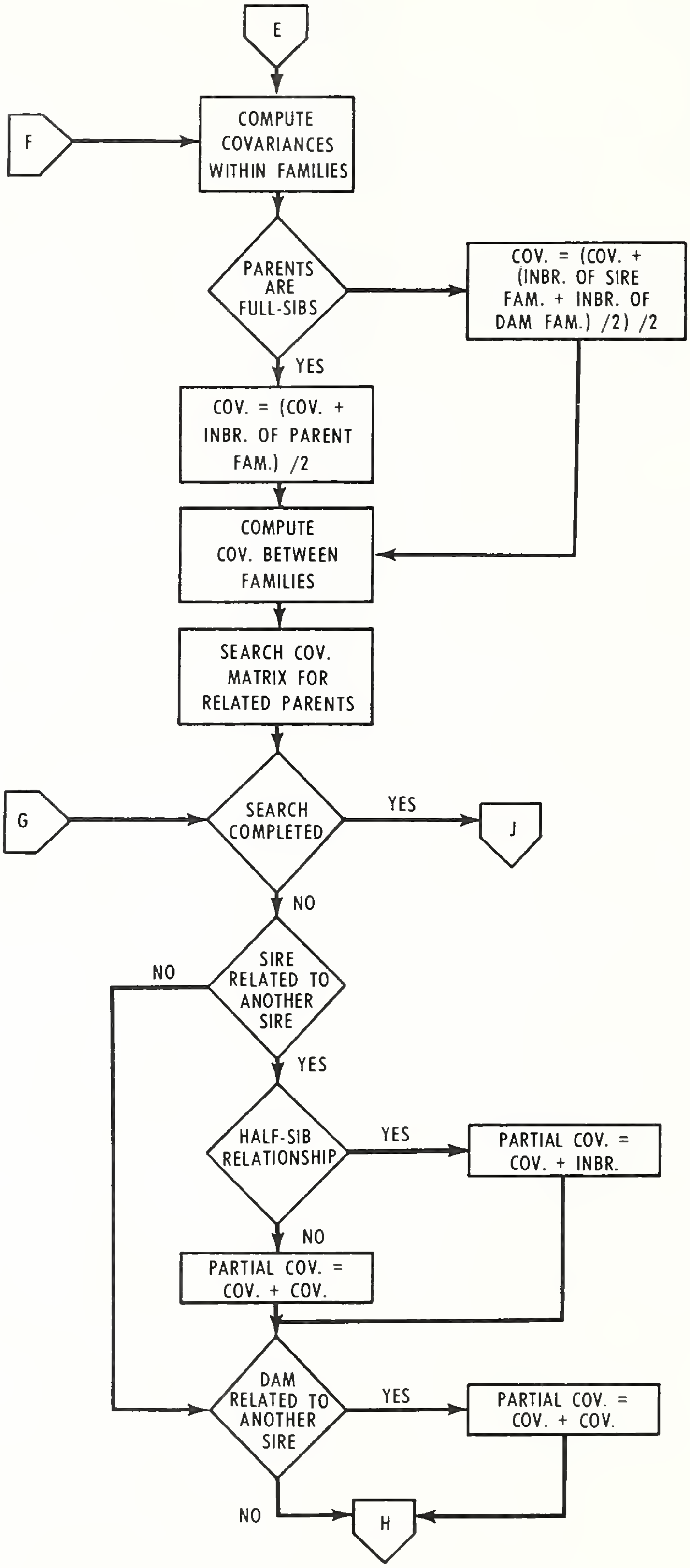
[1] I, Integer; R, real; D, dimension; and E, equivalence.

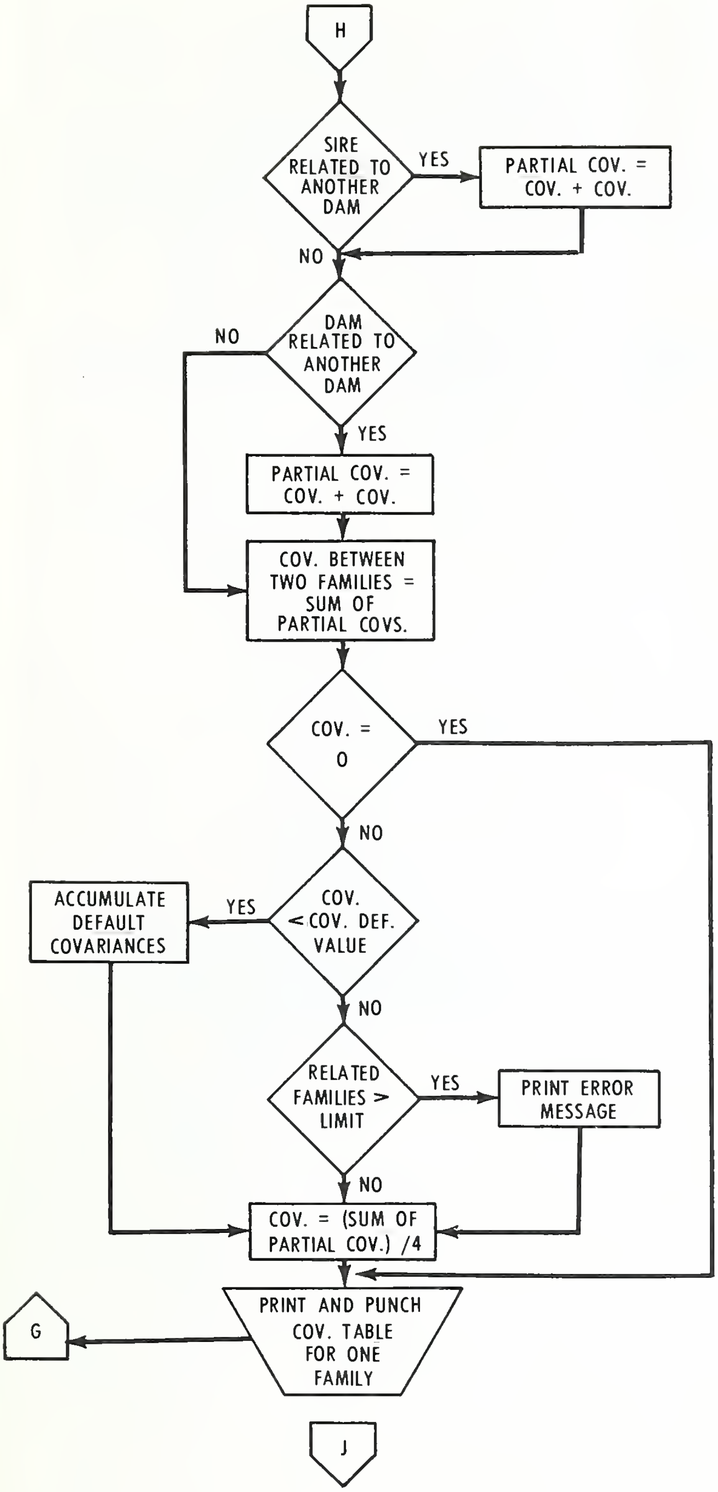
FLOW CHART

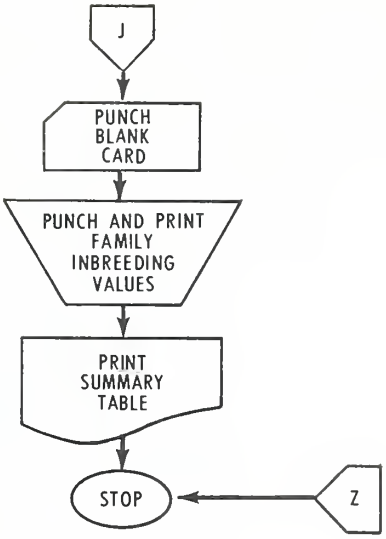

START
READ PARAMETER CARD
INITIALIZE PARAMETER
READ AND STORE PEDIGREE
PARAM. CARD NO. 2
NO
PRINT ERROR MESSAGE
Z
ASSIGN FAMILY CODE TO EACH INDIVIDUAL
SIRE MATED TO MORE THAN 9 DAMS
YES
PRINT ERROR MESSAGE
Z
PUNCH HEADER CARD AND PROGENY CODES
PRINT HEADER CARD AND PROGENY CODES
A


A
FIRST GEN.
NO
B
YES
PUNCH BLANK CARD
COMPARE ALL COMBINATIONS OF FAMILY CODES IN FIRST GEN.
ALL FAMILIES COMPARED
YES
FULL-SIB FAMILY
NO
COVARIANCE=0.5
HALF-SIB FAMILY
NO
YES
COVARIANCE=0.25
PUNCH COVARIANCE MATRIX
PUNCH BLANK CARD
D


D
PRINT COVARIANCES MATRIX AND FAM. INBR.
Z
B
READ AND STORE PROG. CODES FROM PREVIOUS GEN.
READ AND STORE INBR. COEFF. FROM PREVIOUS GEN.
ASSIGN CODES TO PARENTS OF FAM IN CURRENT GEN.
READ AND STORE COV. MATRIX OF PREV. GEN.
SEARCH COV. MATRIX FOR PARENTS OF EACH FAM.
BOTH PARENTS LOCATED
NO
INVALID PEDIGREE
Z
YES
PARENTS RELATED
NO
F (FAMILY) = 1+ AVDROP/2
F
YES
F (FAMILY) = 1+ COVSD/2
E


E
F
COMPUTE COVARIANCES WITHIN FAMILIES
PARENTS ARE FULL-SIBS
COV. = (COV. + (INBR. OF SIRE FAM. + INBR. OF DAM FAM.) /2) /2
YES
COV. = (COV. + INBR. OF PARENT FAM.) /2
COMPUTE COV. BETWEEN FAMILIES
SEARCH COV. MATRIX FOR RELATED PARENTS
G
SEARCH COMPLETED
YES
J
NO
NO
SIRE RELATED TO ANOTHER SIRE
YES
HALF-SIB RELATIONSHIP
YES
PARTIAL COV. = COV. + INBR.
NO
PARTIAL COV. = COV. + COV.
DAM RELATED TO ANOTHER SIRE
YES
PARTIAL COV. = COV. + COV.
NO
H


H
SIRE RELATED TO ANOTHER DAM
YES
PARTIAL COV. = COV. + COV.
NO
DAM RELATED TO ANOTHER DAM
NO
YES
PARTIAL COV. = COV. + COV.
COV. BETWEEN TWO FAMILIES = SUM OF PARTIAL COVS.
COV. = 0
YES
NO
ACCUMULATE DEFAULT COVARIANCES
YES
COV. < COV. DEF. VALUE
NO
RELATED FAMILIES > LIMIT
YES
PRINT ERROR MESSAGE
NO
COV. = (SUM OF PARTIAL COV.) /4
PRINT AND PUNCH COV. TABLE FOR ONE FAMILY
G
J


J
PUNCH BLANK CARD
PUNCH AND PRINT FAMILY INBREEDING VALUES
PRINT SUMMARY TABLE
STOP
Z

```
      PROGRAM MAIN (INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PU
     1NCH)
C
C     PROGRAM TO COMPUTE AVG. INBR. COEFFICIENT USING FAMILY PEDIGREE***
C     PLACE PARAMETER CARD NO. 1 AHEAD OF PEDIGREE DECK*****************
C     OUTPUT FROM PREVIOUS GEN. IS PART OF INPUT FOR CURRENT GEN.*******
C     PLACE **** IBLANK ****CARD BEHIND LAST CARD OF PEDIGREE DECK******
C     PLACE BLANK CARD BEHIND LAST CARD OF DATA DECK********************
C     SORT PEDIGREE DECK BY DAM/SIRE IN ASCENDING ORDER*****************
C
      EQUIVALENCE (ISTORP,ISTORI), (COEFF,INBRDC)
      INTEGER FCODEP,FCODEI
      DIMENSION FCODEP(301), ISTORP(301), FCODEI(301), IR(205,99), IC(20
     15,99), ISTORI(301), IFAMS(250), IFAMD(250), NEWFAM(250), ISIRE(301
     2), IDAM(301), IND(300), IREL(99), ICOV(99), L(251), INDWIN(251), I
     3NBRDP(251), INBRDC(251), COEFF(251)
      DATA IBLANK/6HIBLANK/
C
C     READ PARAMETER CARD NO. 1 WITH GEN. NO.,NO. OF PEDIGREE CARDS,ETC.
C
      READ (5,101) IGEN,NM,NUMREL,NUMFAM,NUMFP1,COVDEF,AVDROP
      NUMINV=0
      KACCUM=0
      INBSUM=0
      COVACC=0.
      ACCNUM=0.
      DO 102 I=1,NUMREL
         IREL(I)=0
  102 ICOV(I)=0
      NMP1=NM+1
      DO 103 I=1,NMP1
         ISIRE(I)=0
         IDAM(I)=0
  103 IND(I)=0
C
C     READ IN PEDIGREE DECK CONTAINING PEDIGREE IDENTIFICATION**********
C     FORMAT STATEMENT NO 104 MAY BE CHANGED TO ACCOMODATE VARIOUS DATA
C     FORMATS.**********************************************************
C
      DO 105 I=1,NM
         READ (5,104) ISIRE(I),IDAM(I),IND(I)
  105 CONTINUE
      READ (5,106) IBLK
      IF (IBLK.EQ.IBLANK) GO TO 108
      WRITE (6,107)
      GO TO 191
  108 DO 109 I=1,NUMFP1
         INBRDC(I)=10000
  109 L(I)=0
C
C     GENERATE FAMILY CODES AND OUTPUT FOR USE IN NEXT GENERATION*******
C
      NFC=0
      NI=0
      DO 115 I=1,60
         DO 112 J=1,9
  110       NI=NI+1
            NIP1=NI+1
            FCODEP(NI)=I*10+J
            ISTORP(NI)=IND(NI)
            IF (IDAM(NI)-IDAM(NIP1)) 111,110,111
  111       NFC=NFC+1
            IF (ISIRE(NI)-ISIRE(NIP1)) 114,112,114
  112     CONTINUE
          WRITE (6,113) ISIRE(NI)
          GO TO 191
  114     IF (ISIRE(NI+1)) 115,116,115
  115 CONTINUE
  116 PUNCH 117, NI,NFC,IGEN
      PUNCH 118, (ISTORP(I),FCODEP(I),I=1,NI)
      PUNCH 119
      WRITE (6,120) NI,NFC,IGEN
      WRITE (6,121)
      WRITE (6,122) (FCODEP(I),ISTORP(I),I=1,NI)
      MALES=FCODEP(NI)/10
      IF (IGEN-1) 123,123,136
C
C     COMPUTE COVARIANCES WITHIN AND BETWEEN FAMILIES IN FIRST GENER.***
C
  123 WRITE (6,124)
      WRITE (6,152)
      DO 132 I=1,NI
        IP1=I+1
        K=1
        IF (FCODEP(I).EQ.FCODEP(IP1)) GO TO 132
        DO 130 J=1,NI
          JP1=J+1
          IF (FCODEP(J).EQ.FCODEP(JP1)) GO TO 130
          IF (FCODEP(I)-FCODEP(J)) 128,127,128
  127     ICOV(1)=5000
          IREL(1)=FCODEP(I)
          GO TO 130
  128     ID10=FCODEP(I)/10
          JD10=FCODEP(J)/10
          IF (ID10-JD10) 131,129,130
  129     K=K+1
          ICOV(K)=2500
          IREL(K)=FCODEP(J)
  130   CONTINUE
  131   PUNCH 134, K,(IREL(L1),ICOV(L1),L1=1,K)
        WRITE (6,126) K,(IREL(M),ICOV(M),M=1,K)
  132 CONTINUE
      PUNCH 119
      PUNCH 139, (INBRDC(J),J=1,NFC)
      DO 133 JP=1,NFC
        COEFF(JP)=INBRDC(JP)
        COEFF(JP)=(COEFF(JP)/10000.)-1.
  133 CONTINUE
      WRITE (6,187) (COEFF(J),J=1,NFC)
      GO TO 191
C
C     READ IN AND STORE FAMILY CODES FROM PREVIOUS GEN.*****************
C
  136 READ (5,137) NIP,NFP
      READ (5,138) (ISTORI(I),FCODEI(I),I=1,NIP)
C
C     READ IN AND STORE INBREEDING COEFFICIENTS FROM PREVIOUS GENERATION
C
      READ (5,139) (INBRDP(J),J=1,NFP)
C
C     ASSIGN CODES TO PARENTS OF FAMILIES IN CURRENT GEN. SO THAT PARENT
```

```
C     OFFSPRING RELATIONSHIPS ARE KNOWN, THUS PERMITTING COVARIANCES
C     AMONG FAMILIES OF THE CURRENT GENERATION TO BE COMPUTED **********
C
      K=0
      NIOLD=0
      DO 144 I=1,NI
         IF (IDAM(I)-IDAM(I+1)) 140,144,140
 140     K=K+1
         INDWIN(K)=I-NIOLD
         NIOLD=I
         DO 141 J=1,NIP
            IF (ISIRE(I).NE.ISTORI(J)) GO TO 141
            IFAMS(K)=FCODEI(J)
            GO TO 142
 141     CONTINUE
         IFAMS(K)=0
 142     DO 143 J=1,NIP
            IF (IDAM(I).NE.ISTORI(J)) GO TO 143
            IFAMD(K)=FCODEI(J)
            NEWFAM(K)=FCODEP(I)
            GO TO 144
 143     CONTINUE
         IFAMD(K)=0
         NEWFAM(K)=FCODEP(I)
 144  CONTINUE
      KCOUNT=K
C
C     READ AND STORE RELATED FAMILIES AND COVARIANCES FROM PREVIOUS GEN.
C
      ND=0
      DO 149 M=1,NUMFP1
         I1=M
         READ (5,147) L(M),(IR(I1,J),IC(I1,J),J=1,9)
         IF (L(M)) 150,150,145
 145     ND=ND+1
         IF (L(M)-9) 149,149,146
 146     LVALUE=L(M)
         READ (5,148) (IR(I1,J),IC(I1,J),J=10,LVALUE)
 149  CONTINUE
 150  WRITE (6,151) IGEN,NM,ND
      WRITE (6,124)
      WRITE (6,152)
C
C     COMPUTE FAMILY INBREEDING COEFFICIENTS****************************
C
      DO 185 LS=1,KCOUNT
         K=1
         COV=0.
         DO 156 LT=1,ND
            IF (IR(LT,1)-IFAMS(LS)) 156,153,156
 153        MATCHS=LT
            LIMIT=L(LT)
            DO 155 INBR=1,LIMIT
               IF (IFAMD(LS)-IR(LT,INBR)) 155,154,155
 154           COV=IC(LT,INBR)
               INBRDC(LS)=(COV/2.)
               INBSUM=INBSUM+INBRDC(LS)*INDWIN(LS)
               INBRDC(LS)=INBRDC(LS)+10000
               IREL(K)=NEWFAM(LS)
               GO TO 157
 155        CONTINUE
```

```
          INBRDC(LS)=(AVDROP/2.)*10000.
          INBSUM=INBSUM+INBRDC(LS)*INDWIN(LS)
          INBRDC(LS)=INBRDC(LS)+10000
          IREL(K)=NEWFAM(LS)
          GO TO 157
  156    CONTINUE
         WRITE (6,161) IFAMS(LS),IFAMD(LS),NEWFAM(LS)
         NUMINV=NUMINV+1
         GO TO 185
C
C     COMPUTE COVARIANCE WITHIN FAMILY**********************************
C
  157    DO 160 LU=1,ND
          IF (IR(LU,1)-IFAMD(LS)) 160,158,160
  158     MATCHD=LU
          IF (IFAMS(LS).NE.IFAMD(LS)) GO TO 159
          X=INBRDP(LU)
          ICOV(K)=(COV+X)/2.
          GO TO 162
  159     X=INBRDP(LT)+INBRDP(LU)
          ICOV(K)=(COV+X/2.)/2.
          GO TO 162
  160    CONTINUE
         WRITE (6,161) IFAMS(LS),IFAMD(LS),NEWFAM(LS)
         NUMINV=NUMINV+1
         GO TO 185
C
C     SEARCH FOR RELATED FAMILIES AND COVARIANCES,PUNCH AND PRINT OUTPUT
C
  162    LIMITS=L(MATCHS)
         LIMITD=L(MATCHD)
         DO 181 N=1,KCOUNT
          COV=0.
          DO 169 LISTRS=1,LIMITS
           IF (IFAMS(N)-IR(MATCHS,LISTRS)) 166,163,166
  163      IF (NEWFAM(N)-NEWFAM(LS)) 164,166,164
  164      CV=IC(MATCHS,LISTRS)
           NFND10=NEWFAM(N)/10
           NFLD10=NEWFAM(LS)/10
           IF (NFND10.NE.NFLD10) GO TO 165
           X=INBRDP(MATCHS)
           COV=COV+X
           GO TO 166
  165      COV=COV+CV
  166      IF (IFAMD(N)-IR(MATCHS,LISTRS)) 169,167,169
  167      IF (NEWFAM(N)-NEWFAM(LS)) 168,169,168
  168      CV=IC(MATCHS,LISTRS)
           COV=COV+CV
  169     CONTINUE
          DO 175 LISTRD=1,LIMITD
           IF (IFAMS(N)-IR(MATCHD,LISTRD)) 172,170,172
  170      IF (NEWFAM(N)-NEWFAM(LS)) 171,172,171
  171      CV=IC(MATCHD,LISTRD)
           COV=COV+CV
  172      IF (IFAMD(N)-IR(MATCHD,LISTRD)) 175,173,175
  173      IF (NEWFAM(N)-NEWFAM(LS)) 174,175,174
  174      CV=IC(MATCHD,LISTRD)
           COV=COV+CV
  175     CONTINUE
          IF (COV) 176,181,176
  176     IF (COV.LE.COVDEF) GO TO 180
```

```
            K=K+1
            IF (K-NUMREL) 179,179,177
  177       WRITE (6,178) NUMREL,NEWFAM(N)
            K=K-1
            GO TO 182
  179       ICOV(K)=COV/4.
            IREL(K)=NEWFAM(N)
            GO TO 181
  180       COVACC=COVACC+COV
            ACCNUM=ACCNUM+1.
  181    CONTINUE
  182    IF (K-9) 183,183,184
  183    PUNCH 134, K,(IREL(M),ICOV(M),M=1,K)
         WRITE (6,126) K,(IREL(M),ICOV(M),M=1,K)
         KACCUM=KACCUM+K
         GO TO 185
  184    PUNCH 134, K,(IREL(M),ICOV(M),M=1,9)
         PUNCH 135, (IREL(M),ICOV(M),M=10,K)
         WRITE (6,126) K,(IREL(M),ICOV(M),M=1,9)
         WRITE (6,125) (IREL(M),ICOV(M),M=10,K)
         KACCUM=KACCUM+K
  185 CONTINUE
      PUNCH 119
      PUNCH 139, (INBRDC(J),J=1,NFC)
C
C     CONVERT COVARIANCES OF INDIVIDUALS WITHIN FAMILIES TO INBR. COEFF.
C
      DO 186 JP=1,NFC
         COEFF(JP)=INBRDC(JP)
         COEFF(JP)=(COEFF(JP)/10000.)-1.
  186 CONTINUE
      WRITE (6,187) (COEFF(J),J=1,NFC)
      D=NM-NUMINV
      IF (D.LT.1.) D=1.
      TOTINB=INBSUM
      AVGINB=(TOTINB/D)/100.
      TOTINB=TOTINB/10000.
      D1=NFC
      AVNODR=ACCNUM/D1
      D2=KACCUM
      AVNORL=(D2+ACCNUM)/D1
      IF (ACCNUM.GT.0.) GO TO 188
      ACCNUM=1.
  188 AVGDRP=(COVACC/4.)/ACCNUM
      AVGDRP=AVGDRP/10000.
      WRITE (6,189)
      WRITE (6,190) IGEN,NM,MALES,NFC,NUMINV,AVNORL,AVNODR,AVDROP,AVGDRP
     1,AVGINB
  191 STOP
C
  101 FORMAT (5I3,F4.0,F4.4)
  104    FORMAT (4XI4,2XI4,2XI4)
  106 FORMAT (A6)
  107 FORMAT ( 55H PARAMETER CARD NO. 2 OMITTED OR INCORRECT VALUE FOR N
     1M)
  113    FORMAT (/5H SIRE,I6,26H MATED TO MORE THAN 9 DAMS/)
  117 FORMAT (I5, 27H PROGENY CODES DERIVED FROM,I4, 21H FAMILIES OF GEN
     1. NO.,I3)
  118 FORMAT (10(2I4))
  119 FORMAT (1H )
  120 FORMAT (1XI5, 27H PROGENY CODES DERIVED FROM,I4, 21H FAMILIES OF G
   1EN. NO.,I3)
121 FORMAT (132H    C O D E    C O D E    C O D E    C O D E    C O D
   1E    C O D E    C O D E    C O D E    C O D E    C O D E    C O D
   2E    C O D E,/)
122 FORMAT (12(1X2I5))
124 FORMAT ( 87H CURRENT GENERATION RELATED FAMILIES AND COVARIANCES W
   1ITHIN AND BETWEEN FAMILIES FOLLOW,/)
125 FORMAT (18X9(I5,I5))
126 FORMAT (/,I5,13X9(I5,I5))
134 FORMAT (I2,9(I3,I5))
135 FORMAT (2X9(I3,I5))
137 FORMAT (I5,27XI4)
138 FORMAT (10(2I4))
139 FORMAT (16I5)
147    FORMAT (I2,9(I3,I5))
148    FORMAT (2X,9(I3,I5))
151 FORMAT (/, 21H CURRENT GENERATION =,I5,/, 21H NO. MASTER CARDS   =
   1,I5,/, 18H PUNCH OUTPUT FROM,I5, 55H FAMILIES IN PREVIOUS GEN. HAS
   2 BEEN READ IN AND STORED.,/)
152 FORMAT (/,108H NO. REL. FAM.      FAM. COV. FAM. COV. FAM. COV. FAM
   1. COV. FAM. COV. FAM. COV. FAM. COV. FAM. COV. FAM. COV.,/)
161    FORMAT ( 64H             INVAL. PEDIGREE-PREVIOUS GEN. PROGENY C
   1   ODE OF SIRE =,I5,  8H OF DAM=,I5, 35H CURRENT GEN. PROGENY CODE
   2    OF IND.=,I4,/)
178       FORMAT ( 46H            NUMBER OF RELATED FAMILIES EXCEEDS,I
   1       4, 38H PROGENY CODE OF NEXT RELATED FAMILY =,I5,/)
187 FORMAT (/, 77H THE FOLLOWING ARE FAMILY INBREEDING COEFFICIENTS FO
   1R THE CURRENT GENERATION.,/(16F6.4))
189 FORMAT (//, 57H1-----------SUMMARY FILE----------SUMMARY FILE-----
   1------,//)
190 FORMAT ( 18H GENERATION NO.  =,I7,//, 18H NO. INDIVIDUALS =,I7,//,
   1 18H NO. OF SIRES    =,I7,//, 18H NO. OF DAMS     =,I7,//, 18H NO.
   2 INVAL. PED. =,I7,//, 49H AVERAGE NUMBER OF RELATED FAMILIES IN TH
   3IS GEN.=,F6.1,//, 49H NO. OF DROPPED COVARIANCES--CURRENT GENERATI
   4ON =,F6.1,//, 49H AVERAGE DROPPED COVARIANCE-PREVIOUS GENERATION =
   5,F8.4,//, 49H AVERAGE DROPPED COVARIANCE--CURRENT GENERATION =,F8.
   64,//, 49H AVERAGE PERCENT INBREEDING--CURRENT GENERATION =,F8.4,/)
    END
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